MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

ENT3056 – ADVANCED FABRICATION TECHNOLOGY
(NE)

11 MARCH 2020
2.30 p.m. – 4.30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 9 pages with 4 Questions only.
2. Attempt **ALL FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. Please refer to APPENDIX at page 8 and 9 for a list of physical constants, a list of formulas, and the error function table.

QUESTION 1

(a) Czochralski (CZ) technique is the main technology used in the growth of monocrystalline silicon (Si) ingot for microelectronic applications. Based on the diagram in Figure 1(a) below, describe the CZ monocrystalline growth process for a doped Si ingot. Explain how doping uniformity, crystal perfection and diameter control for the doped Si ingot can be achieved. [10 marks]

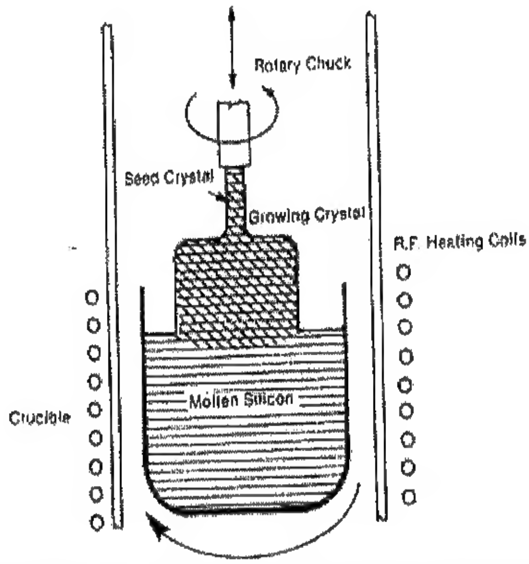

Figure 1(a): Czochralski growth process for single crystal doped silicon.

(b) A silicon (Si) ingot doped with boron (B) is measured for the top wafer slice of the ingot using four-point probe with probe spacing of 1 mm. The voltage/current (V/I) reading obtained is 0.32 Ω. The resistivity versus doping concentration curves for n-type and p-type Si are given in Figure 1(b) and the segregation coefficient for the B dopant is 0.8. Determine the doping concentration of the wafer taken from the position corresponding to 40 % of the initial charge solidified. [6 marks]

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QUESTION 1

(b)

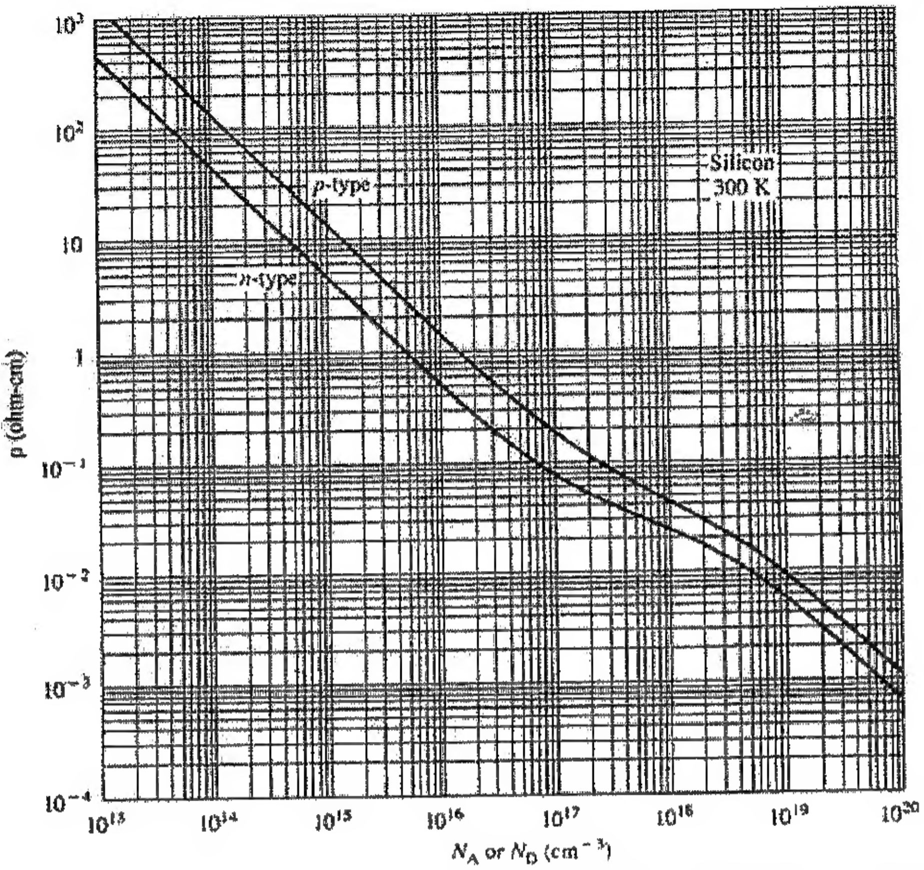

Figure 1(b): Resistivity versus doping concentration curves for n-type and p-type silicon at 300 K, respectively.

(c) Distinguish the characteristics of Physical Vapor Deposition (PVD) technique and Chemical Vapor Deposition (CVD) technique in terms of process reaction and the mechanisms in generating the vapors of the materials to be deposited. [4 marks]

(d) With the aid of a schematic sketch on the equipment setup, describe the operational principles of the magnetron sputtering deposition technique in the microelectronic fabrication. [5 marks]

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QUESTION 2

(a) Semiconductors are key material in the microelectronic industries for fabrication of variety of electronic devices, including diodes, transistors, and integrated circuits. Describe the role of the "doping process" in the semiconductor fabrication. Distinguish the three types of semiconductor material; *Intrinsic Semiconductor*, *Extrinsic Semiconductor*, and *Degenerate Semiconductor*, based on their doping profile. [8 marks]

(b) Provide *ONE* device technology example for the following applications given in Table 2(b), which deploy diffusion process technology. [3 marks]

Table 2(b)

Applications	**Device Technology**
Base	BJT
Emitter	
Resistor	
Source	
Drain	
Polysilicon	
P-N Junction	

(c) Ion implantation is used extensively in the semiconductor technology for a wide range of doping applications. Describe *FIVE* benefits of Ion Implantation compared to Diffusion Technology. [5 marks]

(d) A constant-source diffusion process deploying boron (B) dopant is performed at 1100 °C for 60 minutes on a *N*-type silicon (Si) wafer which has a uniform concentration of 1.017×10^{18} cm^{-3}. The B concentration at the Si surface is 3×10^{19} cm^{-3}. The diffusion coefficient for B at 1100 °C is given as 1×10^{-14} cm^{2}s^{-1}. Determine the junction depth following the constant-source diffusion process. Refer to page 9 for the error function table. [6 marks]

(e) Antimony (Sb) dopant ions are implanted into a silicon (Si) substrate to form a *N*-well region. The projected range of the implanted dopant profile is 1000 Å. Take the standard deviation of the projected range as 600 Å. Given an implantation dose of 1.5×10^{10} cm^{-2}, determine the depth of the peak of the implanted profile, and the peak concentration of the Sb dopant ions. [3 marks]

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QUESTION 3

(a) Photoresist (PR), either positive or negative typed, is a light sensitive organic polymer which becomes soluble or insoluble in a developer solution when exposed to ultraviolet light. Compliment the following performance factors of the positive and negative PR, respectively, given in Table 3(a). [4 marks]

Table 3(a)

Performance factors	**Negative PR**	**Positive PR**
Resolution		
Etch Resistance		
Thermal Stability		
Reliability		

(b) Describe *TWO* advantages and disadvantages, respectively, of a projection printer in optical lithography. Given a projection printer with a deep ultraviolet (DUV) light from excimer laser with a wavelength of 248 nm, assuming a resist constant, k, of 0.7 and a numerical aperture, NA, of 0.25, determine the best resolution achievable with the projection printer. [6 marks]

(c) Figure 3(c) depicts the applications of lithography to pattern the implantation areas, deposit metal features and etch areas. Illustrate the resultant structures following the implantation, deposition and etching process, respectively. [6 marks]

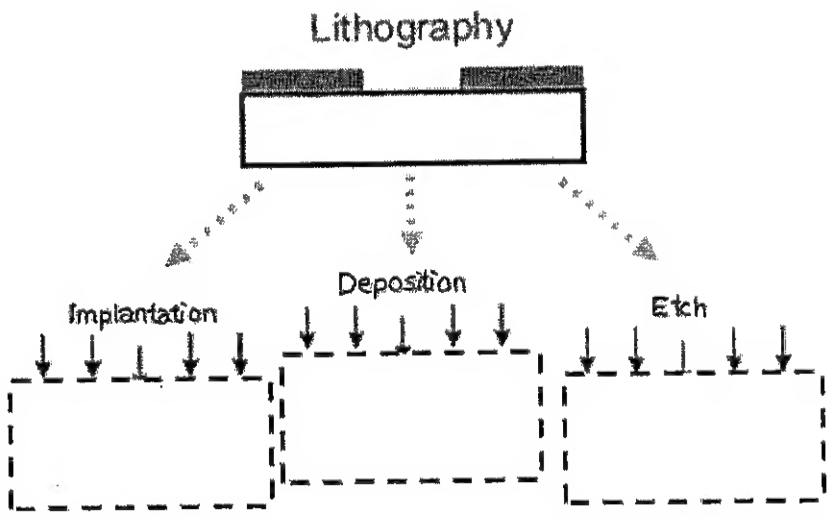

Figure 3(c): Applications of lithography to pattern the implantation areas, deposit metal features and etch areas.

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QUESTION 3

(d) Figure 3(d) shows the schematic cross-section of a pn-junction diode on p-Si substrate. Design the fabrication process for the pn-junction diode by sketching the cross-sectional structure upon each of the process step, starting from the p-Si substrate. Label the structures and briefly state the respective processes. [9 marks]

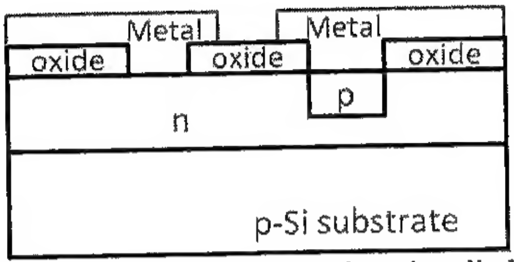

Figure 3(d): Schematic cross-section of a pn-junction diode on p-Si substrate.

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QUESTION 4

(a) Identify the *THREE* levels of interconnection for interconnecting the devices and circuits in the realization of integrated circuits (ICs). [3 marks]

(b) Elaborate the overwhelming rationale of the copper (Cu) metallization to replace the aluminum (Al) metallization in the interconnects for ICs. Describe the weaknesses of the Cu metallization, in spite of the inevitable deployment of the scheme in the high density ICs. Propose solutions to overcome the weaknesses of the Cu metallization scheme. [6 marks]

(c) In order to improve the device switching speed, a metallization scheme with aluminum (Al) (ρ = 2.7 μΩ-cm) metal layer on silicon oxide (SiO_2) (k = 3.9) gate dielectric is replaced with copper (Cu) (ρ = 1.7 μΩ-cm) metal layer on fluorine-doped oxide (k = 3.5) gate dielectric. Determine the percentage of reduction in the resistance-capacitance (R-C) time constant delay with such a replacement in the metallization scheme. [3 marks]

(d) Determine the film thickness of a tungsten silicide (WSi) film for a desired sheet resistance of 0.5 ohm/square. Assume that the WSi film resistivity is 50 μohm-cm. [3 marks]

(e) Sketch the I-V characteristics of an Ohmic Contact, Schottky Contact, and a practical Ohmic Contact, respectively. Describe the contact properties of these three types of contacts in ICs. [6 marks]

(f) Describe the Aluminum-Silicon (Al-Si) Eutectic Behavior, for which the Al must be introduced into the ICs process sequence after all high-temperature processing steps have been completed. [4 marks]

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APPENDIX (Physical Constants):

Avogadro number, $N_{avo} = 6.02217\times10^{23}$ mol^{-1}
Boltzmann constant, $k = 1.380622\times10^{-23}$ J K^{-1} = 8.61712×10^{-5} eV K^{-1}
Electronic charge, $e = 1.60219\times10^{-19}$ C
Electron rest mass, $m_o = 9.10956\times10^{-31}$ kg
Electron volt, 1 eV = 1.60219×10^{-19} J
Si yield strength = 2×10^{7} dynes cm = 7 GPa
Latent heat of fusion for Si, L = 340 cal g^{-1}
Thermal conductivity of Si, k = 0.21 W cm^{-1} °C^{-1}
Amount of heat of 1 calorie = 4.14 J
Density of bulk Si = 2.33 g cm^{-3}
Density of molten Si = 2.53 g cm^{-3}
Electric current of 1 A = 1 Cs^{-1}
Atomic mass unit of 1 amu = 1.66053×10^{-27} kg
Magnetic flux density of 1 T = 1 Wb m^{-2} = 10^{4} G
Angstrom unit of 1 Å = 1×10^{-10} m = 0.1 nm = 1×10^{-4} μm
Permittivity of free space = 8.85×10^{-14} F cm^{-1}
Pressure of 1 Torr = 133.32237 Pa

Formulas:

$X_j = R_p \pm \Delta R_p \sqrt{2\ln(N_p/N_B)}$	$N(x) = \frac{Q_o}{\sqrt{2\pi}\Delta R_p} e^{\left[-\frac{1}{2}\left(\frac{x-R_p}{\Delta R_p}\right)^2\right]}$
$x_j = 2\sqrt{Dt}\ \ln(N_o/N_B)$	$N(x,y) = \frac{N(x)}{\sqrt{2\pi}\Delta R_\perp} e^{\left[-\frac{y^2}{2\Delta R_\perp^2}\right]}$
$x_j = 2\sqrt{Dt}\ erfc^{-1}(N_B/N_o)$	$C_s = \frac{Q}{\sqrt{\pi Dt}}$
$RC = \frac{R_s L^2 \in_{gd}}{d_{gd}} = \frac{\rho}{d_{poly-si}} \frac{L^2 \in_{gd}}{d_{gd}}$	$Q = 2C_s\sqrt{\frac{Dt}{\pi}}$
$C(x,t) = C_s erfc\left[\frac{x}{2\sqrt{Dt}}\right]$	$Q = \sqrt{2\pi} N_p \Delta R_p$
$C(x) = \frac{Q}{\sqrt{\pi Dt}} e^{-\left(\frac{x}{2\sqrt{Dt}}\right)^2}$	$C = k\, C_0\, (1-x)^{k-1}$
$W_{min} = k\,\{\lambda / NA\}$	$W_{min} = \sqrt{k\lambda g}$
$R_c = \rho_c / A$, $\rho = Rs \cdot t$, $\rho = 2\pi s\left(V/I\right)$	$k_0 = \frac{C_s}{C_l}$

Continued……

Values of the error function $\operatorname{erf}(t)=\frac{2}{\sqrt{\pi}}\int_0^t e^{-a^2}\,da$

t	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.0113	0.0226	0.0338	0.0451	0.0564	0.0676	0.0789	0.0901	0.1013
0.1	0.1125	0.1236	0.1348	0.1459	0.1569	0.1680	0.1790	0.1900	0.2009	0.2118
0.2	0.2227	0.2335	0.2443	0.2550	0.2657	0.2763	0.2869	0.2974	0.3079	0.3183
0.3	0.3286	0.3389	0.3491	0.3593	0.3694	0.3794	0.3893	0.3992	0.4090	0.4187
0.4	0.4284	0.4380	0.4475	0.4569	0.4662	0.4755	0.4847	0.4937	0.5027	0.5117
0.5	0.5205	0.5292	0.5379	0.5465	0.5549	0.5633	0.5716	0.5798	0.5879	0.5959
0.6	0.6039	0.6117	0.6194	0.6270	0.6346	0.6420	0.6494	0.6566	0.6638	0.6708
0.7	0.6778	0.6847	0.6914	0.6981	0.7047	0.7112	0.7175	0.7238	0.7300	0.7361
0.8	0.7421	0.7480	0.7538	0.7595	0.7651	0.7707	0.7761	0.7814	0.7867	0.7918
0.9	0.7969	0.8019	0.8068	0.8116	0.8163	0.8209	0.8254	0.8299	0.8342	0.8385
1.0	0.8472	0.8468	0.8508	0.8548	0.8586	0.8624	0.8661	0.8698	0.8733	0.8768
1.1	0.8802	0.8835	0.8868	0.8900	0.8931	0.8961	0.8991	0.9020	0.9048	0.9076
1.2	0.9103	0.9130	0.9155	0.9181	0.9205	0.9229	0.9252	0.9275	0.9297	0.9319
1.3	0.9340	0.9361	0.9381	0.9400	0.9419	0.9438	0.9456	0.9473	0.9490	0.9507
1.4	0.9523	0.9539	0.9554	0.9569	0.9583	0.9597	0.9611	0.9624	0.9637	0.9649
1.5	0.9661	0.9673	0.9684	0.9695	0.9706	0.9716	0.9726	0.9736	0.9746	0.9755
1.6	0.9764	0.9772	0.9780	0.9789	0.9796	0.9804	0.9811	0.9818	0.9825	0.9832
1.7	0.9838	0.9844	0.9850	0.9856	0.9861	0.9867	0.9872	0.9877	0.9882	0.9886
1.8	0.9891	0.9895	0.9899	0.9904	0.9907	0.9911	0.9915	0.9918	0.9922	0.9925
1.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
2.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
2.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
2.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
2.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
2.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
2.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
2.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
2.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99998	.99998	.99998	.99998	.99998	.99998	.99999	.99999	.99999

for $t > 3$ $\quad \operatorname{erf}(t)\approx 1-\frac{1}{\sqrt{\pi}\,t}\exp\left(-t^2\right)$

For Complementary Error Function, erfc (t) = 1 - erf (t)

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